

B Tagging and Mixing at Tevatron

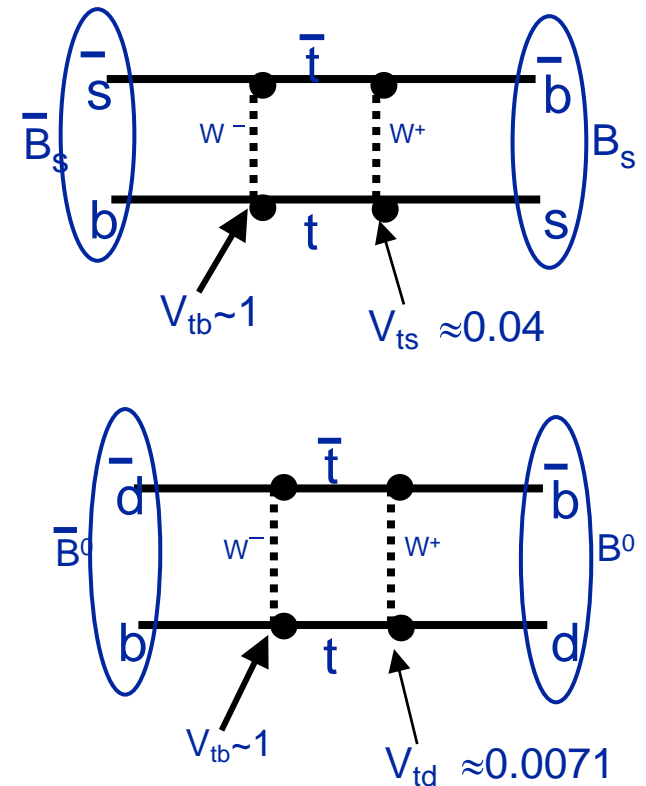
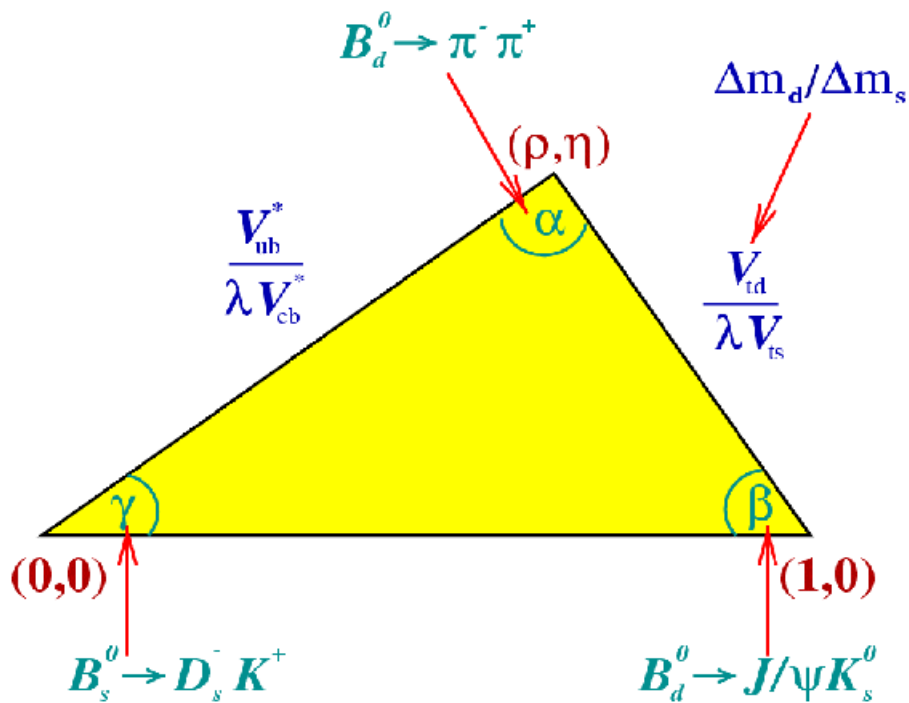
(Focusing on B_s mixing prospect)

Ting Miao (FNAL)

- **Key issues for B mixing analyses**
- **Current flavor tagging and B_s yield results**
- **Prospect in the next few years**

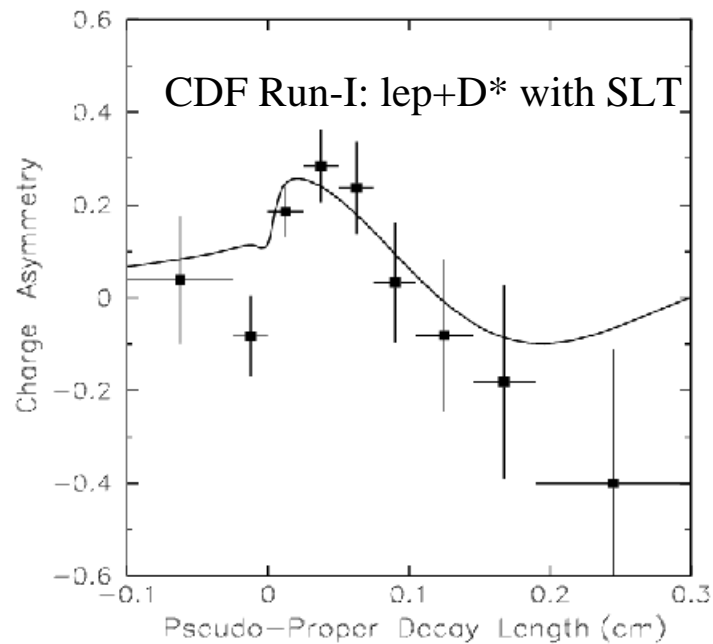
B mixing and CKM matrixes

- $\Delta m_s / \Delta m_d = (M_{B_s} / M_{B^0}) \xi |V_{ts} / V_{td}|^2$
- Exploring one side of CKM triangle



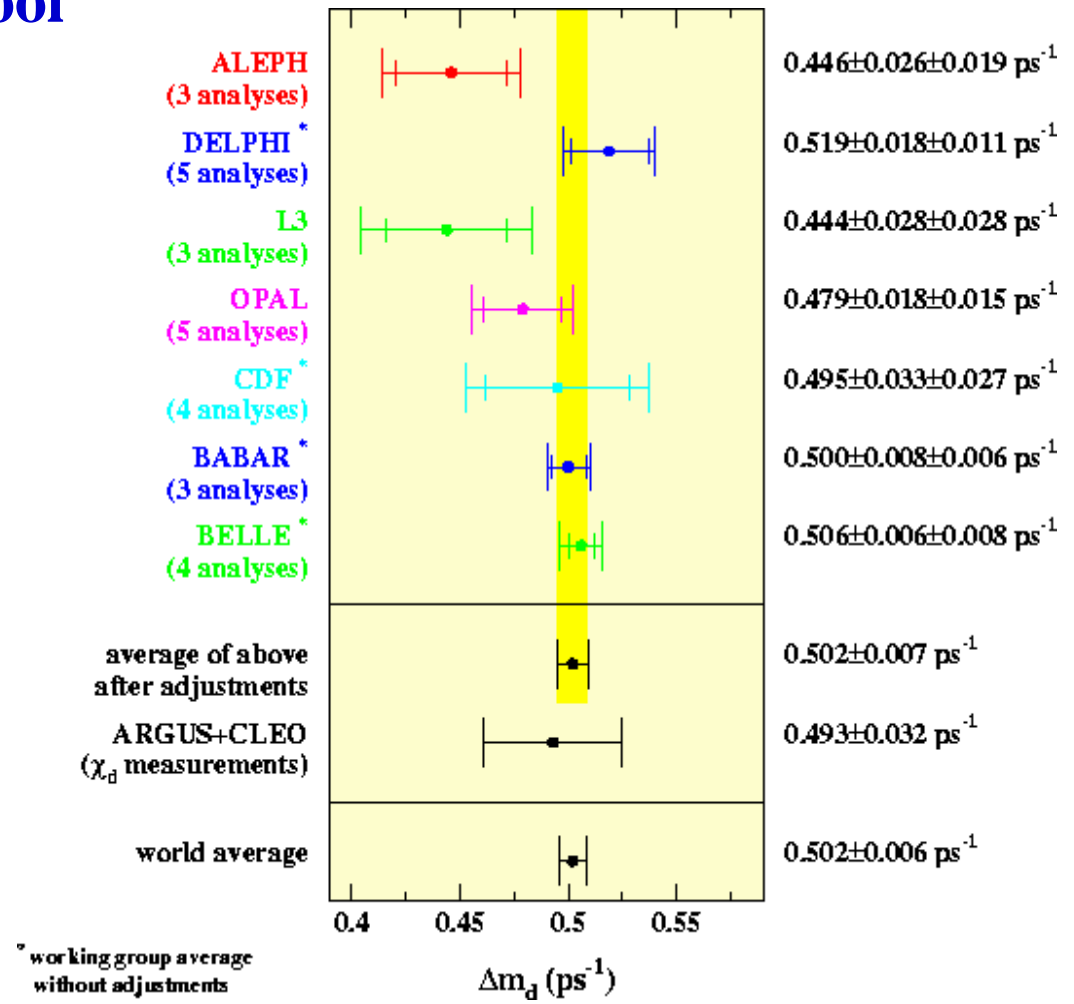
B^0 mixing

Δm_d is well measured and serves
CDF/D0 as nice calibration tool



$$\Delta m_d = 0.512 \pm 0.09 \pm 0.04 \text{ ps}^{-1}$$

$$\Delta m_d = 0.502 \pm 0.006 \text{ ps}^{-1} \text{ (HFAG 2003)}$$



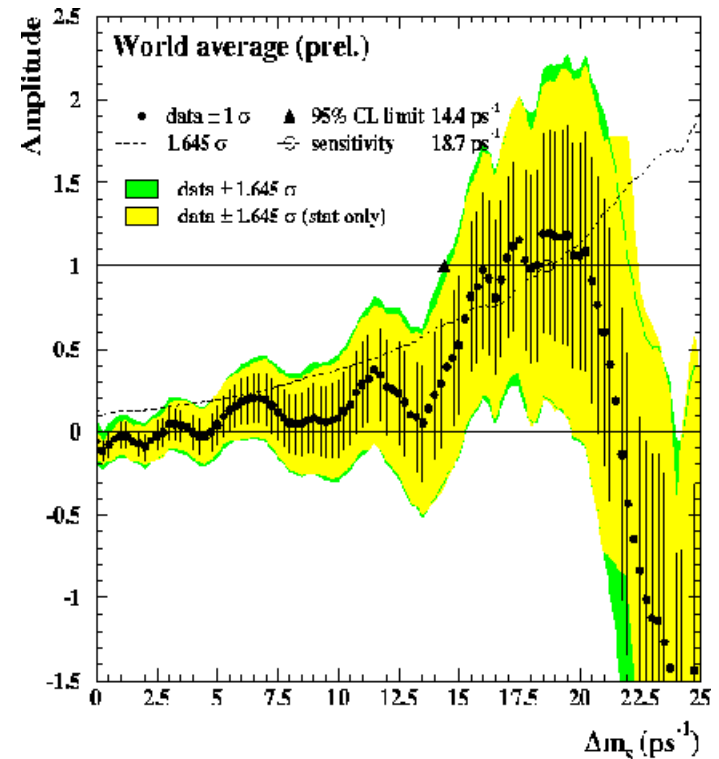
Bs mixing

- B_s mixing is the top priority for B physics at Tevatron
- A challenging measurement due to the rapid oscillation

$$\Delta m_s > 14.4 \text{ ps}^{-1} @ 90\% \text{ CL (HFAG 03)}$$

4 oscillations per lifetime cycle

- Unique Tevatron opportunity

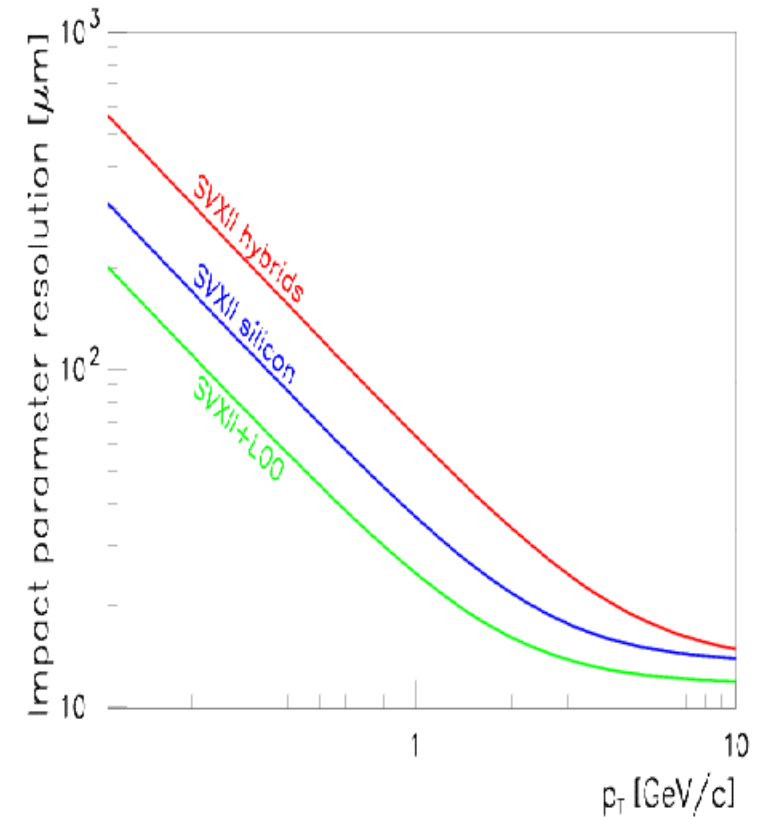
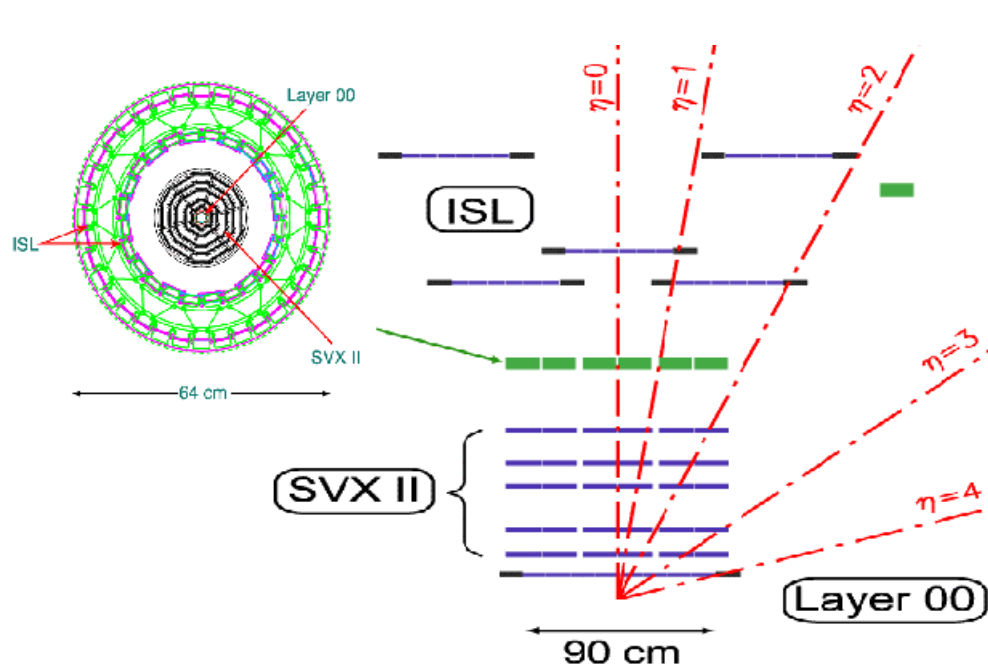


Combined limits of indirect measurements using amplitude methods from LEP, SLD & CDF Run I

Key issues for Bs mixing

- **High statistics with good signal-to-background ratio**
 - Efficient triggering and fine mass resolution
 - Trigger on high pT leptons and displaced tracks (SVT/STT)
- **Efficient Initial B flavor identification**
 - Only 20-40% chance for both B in the detector acceptance
 - e/ μ coverage (SLT), tracking (JetQ/SST) and PID (Kaon)
- **Excellent proper decay length**
 - Momentum and vertex resolution
 - Utilize the fully reconstructed decays

CDF Silicon Detector



- 8 layers with improved 3D ability
- L00 improves impact parameter resolution by 30-50%
- ISL extends tracking coverage for e/μ systems to $|\eta|=2$

CDF Silicon Vertex Trigger at Level-2

- **Trigger on displaced tracks from b**

L1 track + Si hits = L2 SVT

- **Excellent L2 impact parameter resolution**

$$\sigma = 35\mu\text{m} \oplus 33\mu\text{m} (\text{resol} \oplus \text{beam}) = 48\mu\text{m}$$

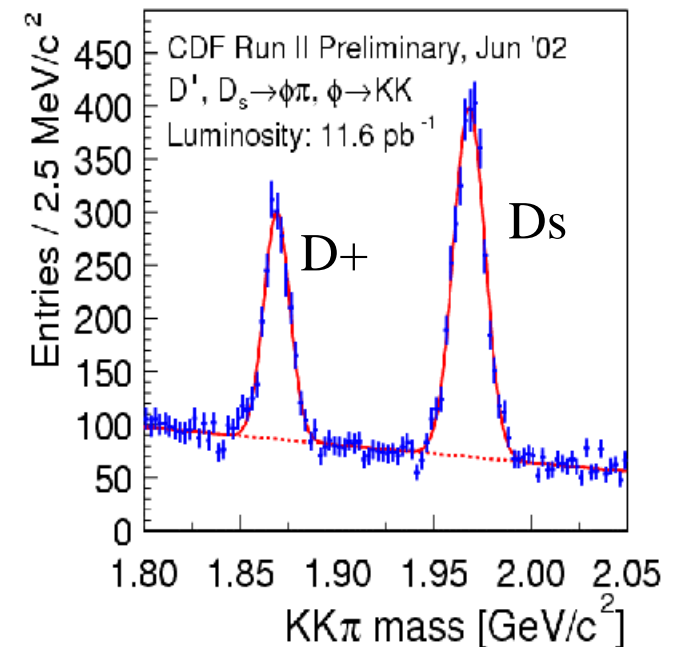
- **2-track trigger for $B_s \rightarrow D_s \pi$ etc.**

Tracks: $p_T > 2 \text{ GeV}$, $d_0 > 120 \mu\text{m}$

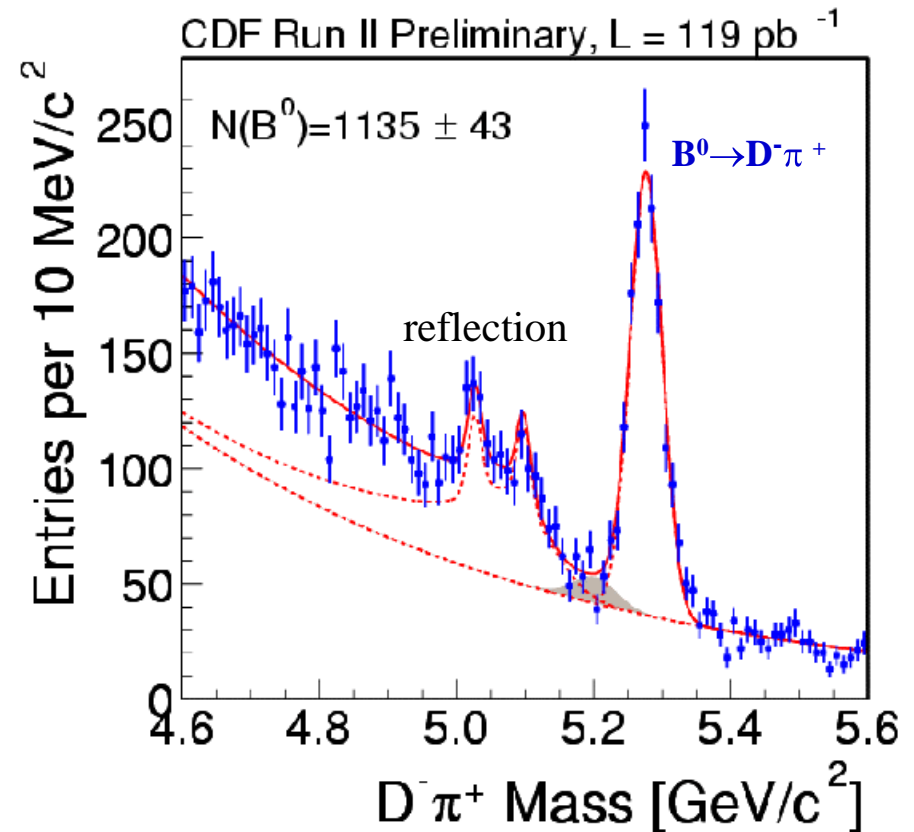
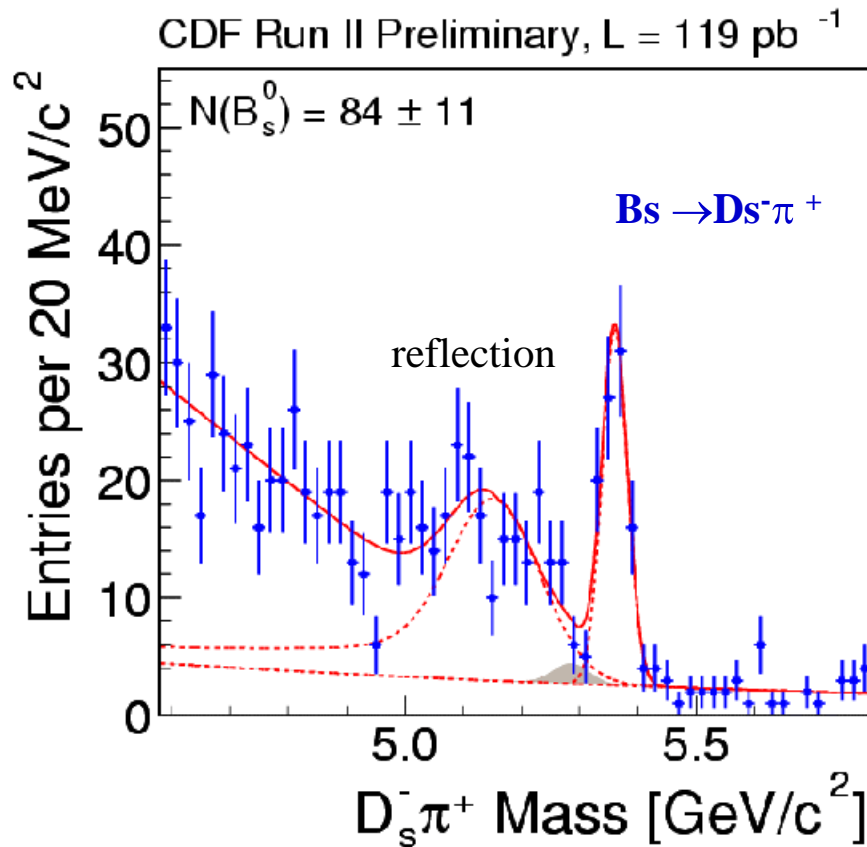
- **e/μ + displaced track trigger**

$p_T(e/\mu) > 4 \text{ GeV}$ with $p_T(\text{track}) > 2 \text{ GeV}$, $d_0 > 120 \mu\text{m}$

First Run II paper!



$B_s \rightarrow D_s \pi$ reconstruction



700 event per fb^{-1} of $B_s \rightarrow D_s \pi$ with $D_s \rightarrow \phi \pi$, $\phi \rightarrow K^+ K^-$

$\text{Br}(B_s \rightarrow D_s^- \pi^+) / \text{Br}(B^0 \rightarrow D^- \pi^+) = 1.4 \pm 0.2(\text{stat}) \pm 0.2(\text{syst}) \pm 0.4(\text{Br}) \pm 0.2(\text{PR})$

Bs → Ds π yield (CDF)

Results so far are using early CDF data

Detector coverage and SVT efficiency improved since

SVX-II coverage (now ~90%)

SVT hits requirement optimization (4/4 → 4/5)

Better use of L2 trigger bandwidth (dynamic pre-scales)

We are seeing a factor of 2 increase on Bs yield

Current condition produces Bs at a rate 1600/fb⁻¹

Not count additional Bs/Ds channels yet

$B_s \rightarrow D_s \pi^+ \pi^- \pi^+ \pi^- / D_s \rightarrow K^* K, K_s K$

Proper time resolution (CDF)

- $\sigma_t = (\sigma_{L_{xy}}/\beta\gamma) \oplus (\sigma_{pT}/pT) \cdot t$
 - Proper time $t = L_{xy} / \beta\gamma$, $\beta\gamma = m / pT$
- $\sigma_{L_{xy}}$ dominates for fully reconstructed events
- $\sigma_{pT}/pT = 15\%$ for semileptonic decay
- From $B_s \rightarrow D_s \pi$ sample $\sigma_{L_{xy}} \approx 50 \mu\text{m}$ with run-averaged beam line and without using L00 hits
 - $\sigma_{l_{xy}} \approx 40 \oplus 30 \mu\text{m}$ (SVX \oplus beam)
- $\sigma_t = 0.067 \text{ ps}$ now for $B_s \rightarrow D_s \pi$
- $\sigma_t = 0.050 \text{ ps}$ achievable (L00+event-by-event beam line)

Initial B flavor tagging at CDF/D0

- **Soft lepton tagging (SLT)**
 - Semileptonic decay from the 2nd B
 - High purity and lepton can be part of a trigger
- **Jet Charge Tagging (JetQ)**
 - Correlation of b-flavor and charge of a b-jet
 - High efficiency but Low purity
- **Opposite-side Kaon Tagging (OKT)**
 - $N(B^0/B^+ \rightarrow K^+)/N(B^0/B^+ \rightarrow K^-) \approx 5$ due to the $b \rightarrow c \rightarrow s$
 - Need PID for tagging purity

Flavor tagging at CDF/D0

- **Same Side Tagging (SST)**

$(\pi^- B^+, \pi^+ B^0, K^+ B_s)$ correlations from b fragmentation or from B^{**} decays

- No need for 2nd B in the acceptance
- High efficiency and reasonable purity
- PID will enhance purity

- **$\epsilon D^2 =$ effective tagging efficiency**

- $\epsilon = N_{\text{tag}}/N_{\text{total}}$ (efficiency of finding a tagger)
- $D = (N_R - N_W)/N_{\text{tag}}$ (ability for a right decision)

Flavor tagging results from D0

• Tested on $B^+ \rightarrow J/\psi K^+$ events

SST: $\epsilon D^2 = (5.5 \pm 2.0)\%$

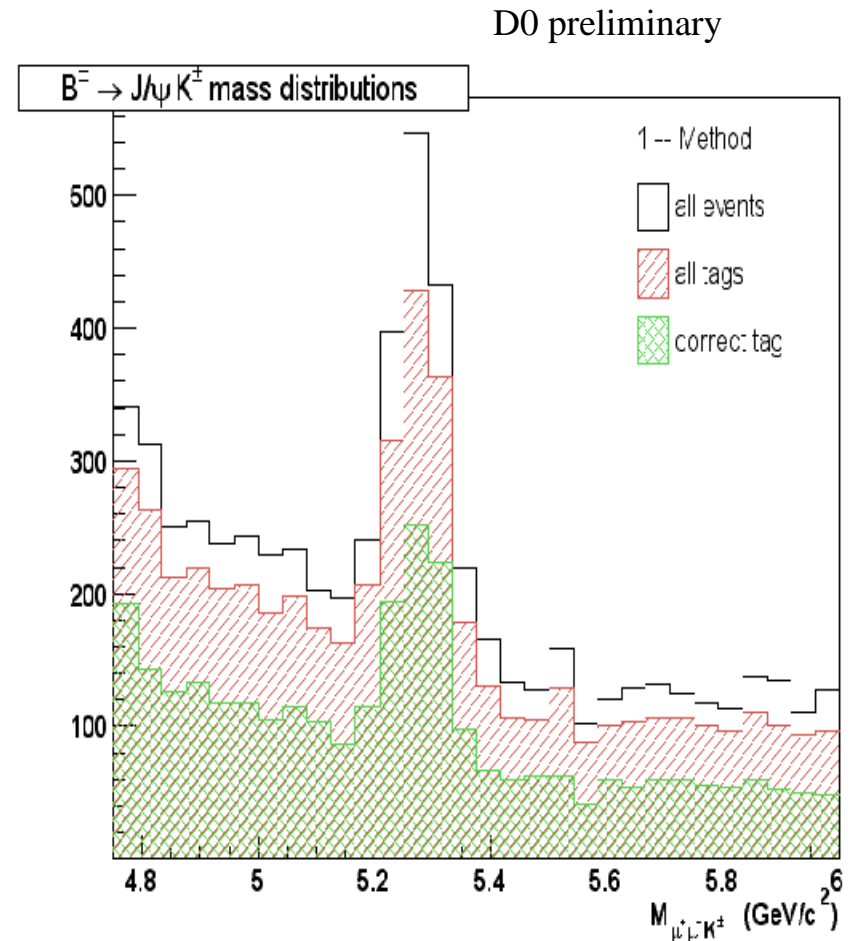
($\epsilon = 79.2 \pm 2.1\%$ and $D = 26.4 \pm 4.8\%$)

Muon: $\epsilon D^2 = (1.6 \pm 1.1)\%$

($\epsilon = 5.0 \pm 0.5\%$ and $D = 57.0 \pm 19.3\%$)

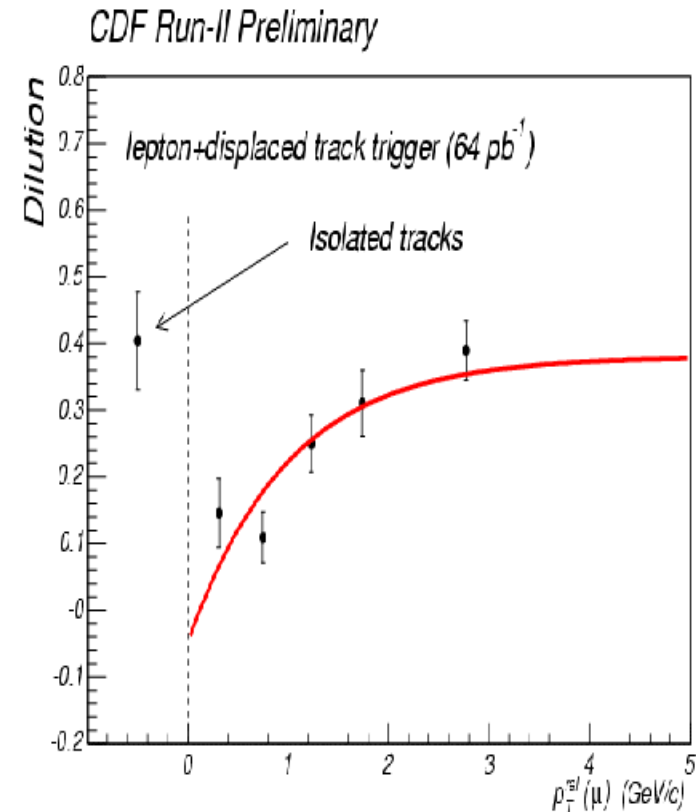
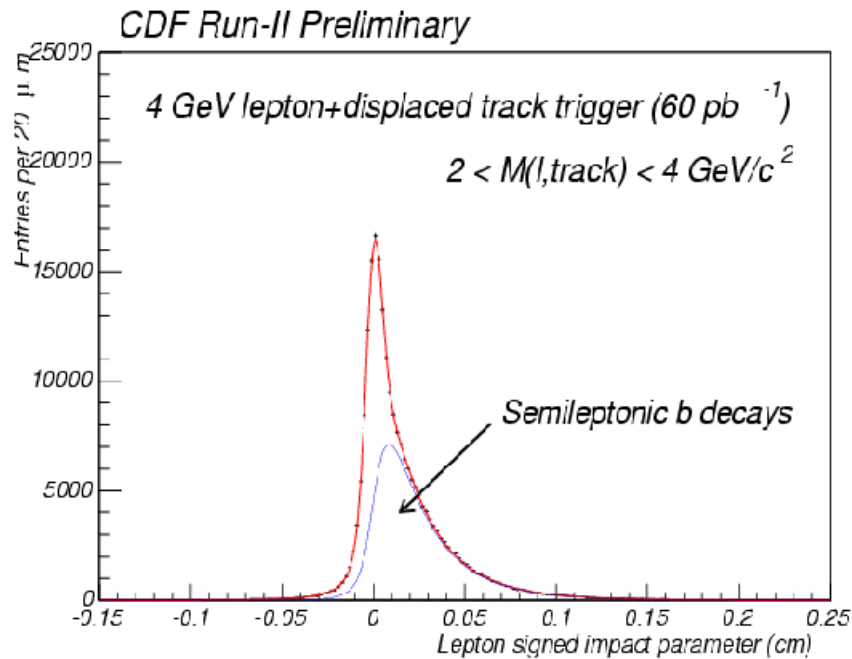
Jet-Q: $\epsilon D^2 = (3.3 \pm 1.7)\%$

($\epsilon = 46.7 \pm 2.7\%$ and $D = 26.7 \pm 6.8\%$)



SLT result from CDF

• Test on high statistics l +SVT events



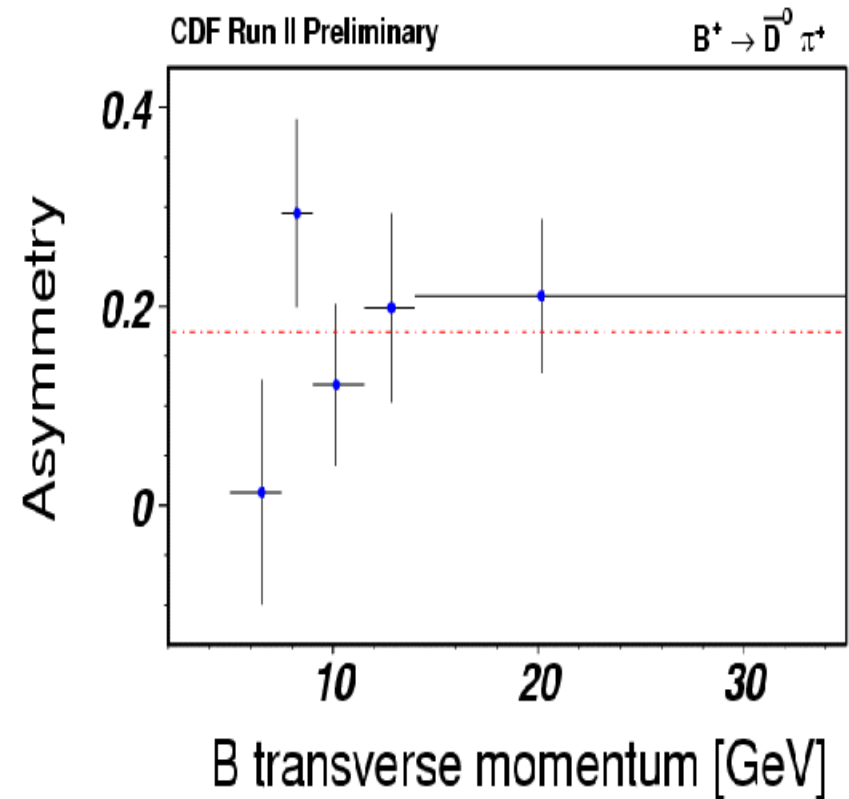
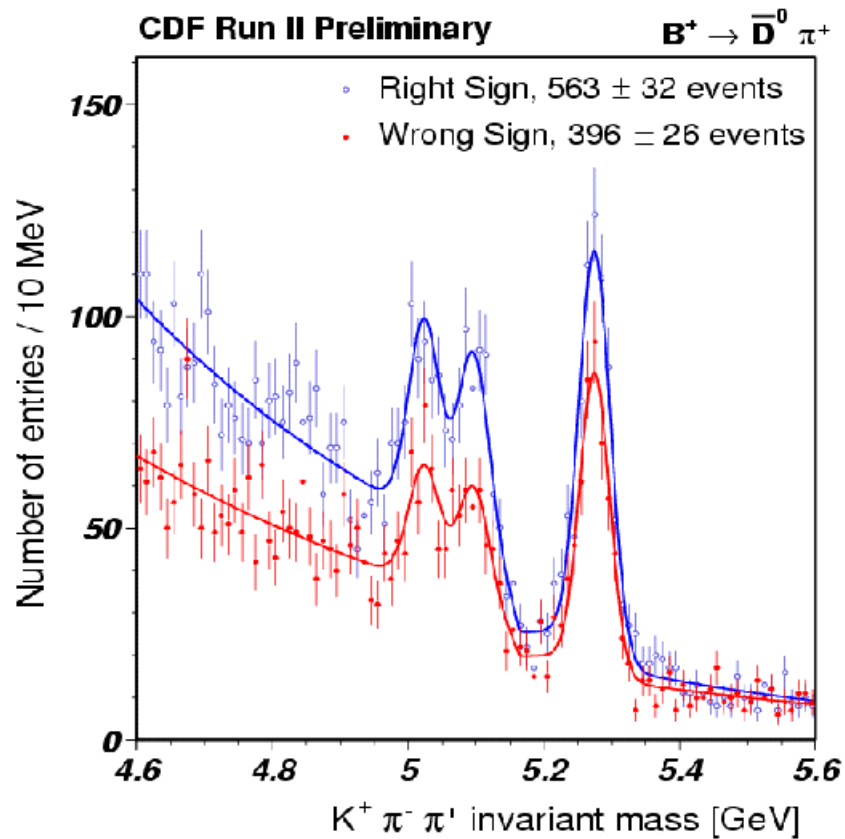
- Need to correct the Dilution (64%) from triggered lep+SVT pair due to mixing and charm/prompt background

Tagging efficiency:

$$\epsilon D^2(\mu) = (0.7 \pm 0.1)\% \quad (\epsilon = 1\%)$$

SST result from CDF

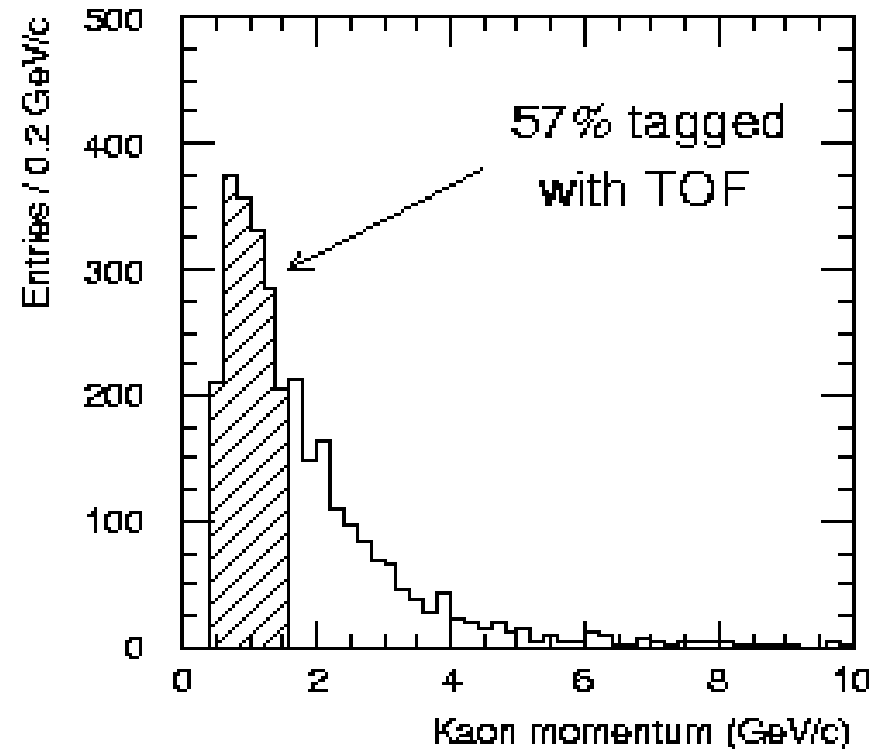
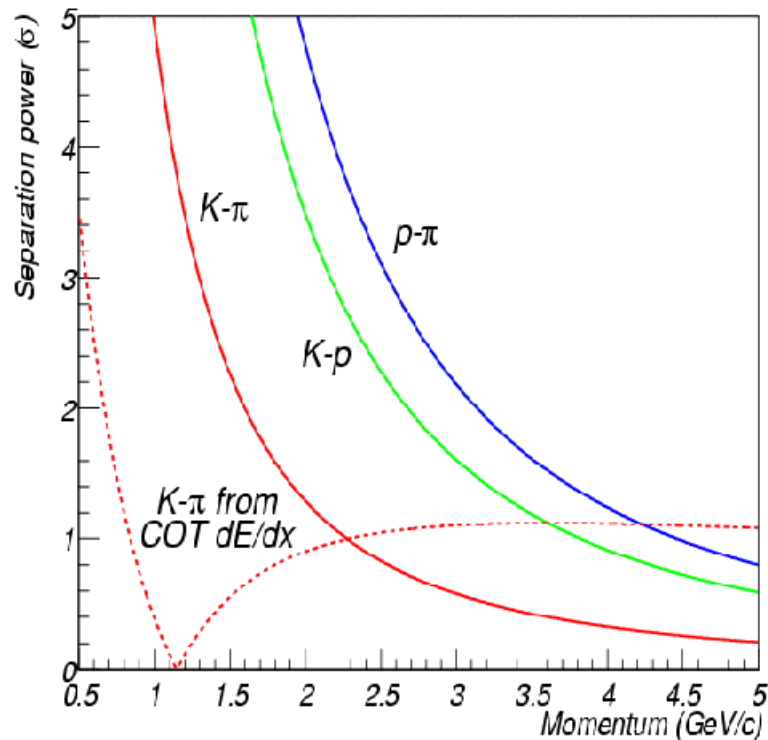
SST on $B^+ \rightarrow J/\psi K^+$ and $B^+ \rightarrow D^0 K^+$



$$\epsilon D^2 = (2.1 \pm 0.7)\% \quad (\epsilon \sim 62\%)$$

TOF and flavor tagging

- **TOF has big effect on tagging purity**
 - 2σ K- π separation for $p < 1.6$ GeV/c which covers $\sim 57\%$ of the B tracks
 - Important for both OKT and SST-K ($\epsilon_{D^2} \rightarrow 4.2\%$ for SST)



Tagger Summary (CDF)

$\epsilon D^2(\%)$	Run-I	Run-II	Projection w/o TOF	Projection with TOF	Key improvement
SST- π/K	1.5 ± 0.4	2.1 ± 0.7	2.0	2.0 - 4.2	SVX/TOF
SLT- μ	0.6 ± 0.1	0.7 ± 0.1	1.0	1.0	CMX/IMU/ISL
SLT-e	0.3 ± 0.1		0.7	0.7	Plug Cal/ISL
JetQ	1.0 ± 0.3		3.0	3.0	COT/SVX
OKT				2.4	TOF

- Measurements with early data are consistent with projections
- Update soon with improved detector coverage and performance
- **Projection for CDF Bs mixing sensitivity will use:**

$\epsilon D^2 = 4\%$ (w/o TOF) $\rightarrow 5\%$ (with TOF)

Bs mixing sensitivity formula

$$Significance = \sqrt{\frac{S \varepsilon D^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S + B}}$$

S = number of signal events

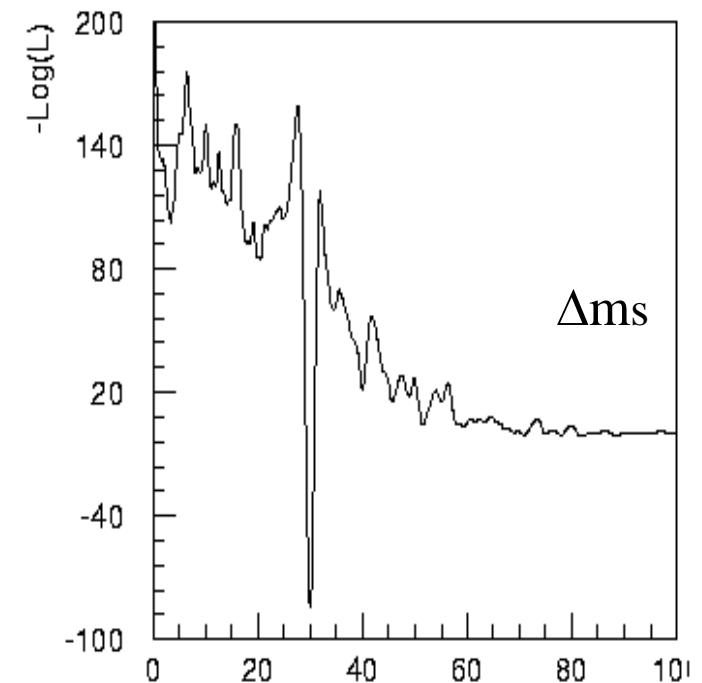
S/B = signal/background ratio

σ_t = proper time resolution

εD^2 = effective tagging efficiency

- It is the “averaged” significance of analyses using likelihood fittings

$$significance = \sqrt{2\Delta \log L} \Rightarrow$$



CDF Bs mixing prospect with 500pb⁻¹

With current performance

$$S=1600 \text{ event/fb}^{-1}$$

$$S/B=2/1$$

$$- \epsilon D^2 = 4\% \text{ (SLT+SST+JetQ)}$$

$$- \sigma_t = 0.067 \text{ ps}$$

- **2 σ measurement if $\Delta m_s=15 \text{ ps}^{-1}$ from 500pb⁻¹ data**

- Expect 590pb⁻¹ - 680pb⁻¹ from Tevatron by 2004

- Beat current limit from indirect measurements

- Reach Standard Model favored region

CDF Bs mixing prospect with 2fb⁻¹

- **Expect Tevatron to deliver luminosity of**
 - 2.11fb⁻¹ (based line) and 3.78fb⁻¹(design) by 2007

With modest improvement for CDF

Add $D_s \rightarrow K^*K$, K_sK and $B_s \rightarrow D_s\pi + \pi -\pi +$

$S=1600 \rightarrow 2000 \text{ event/fb}^{-1}$

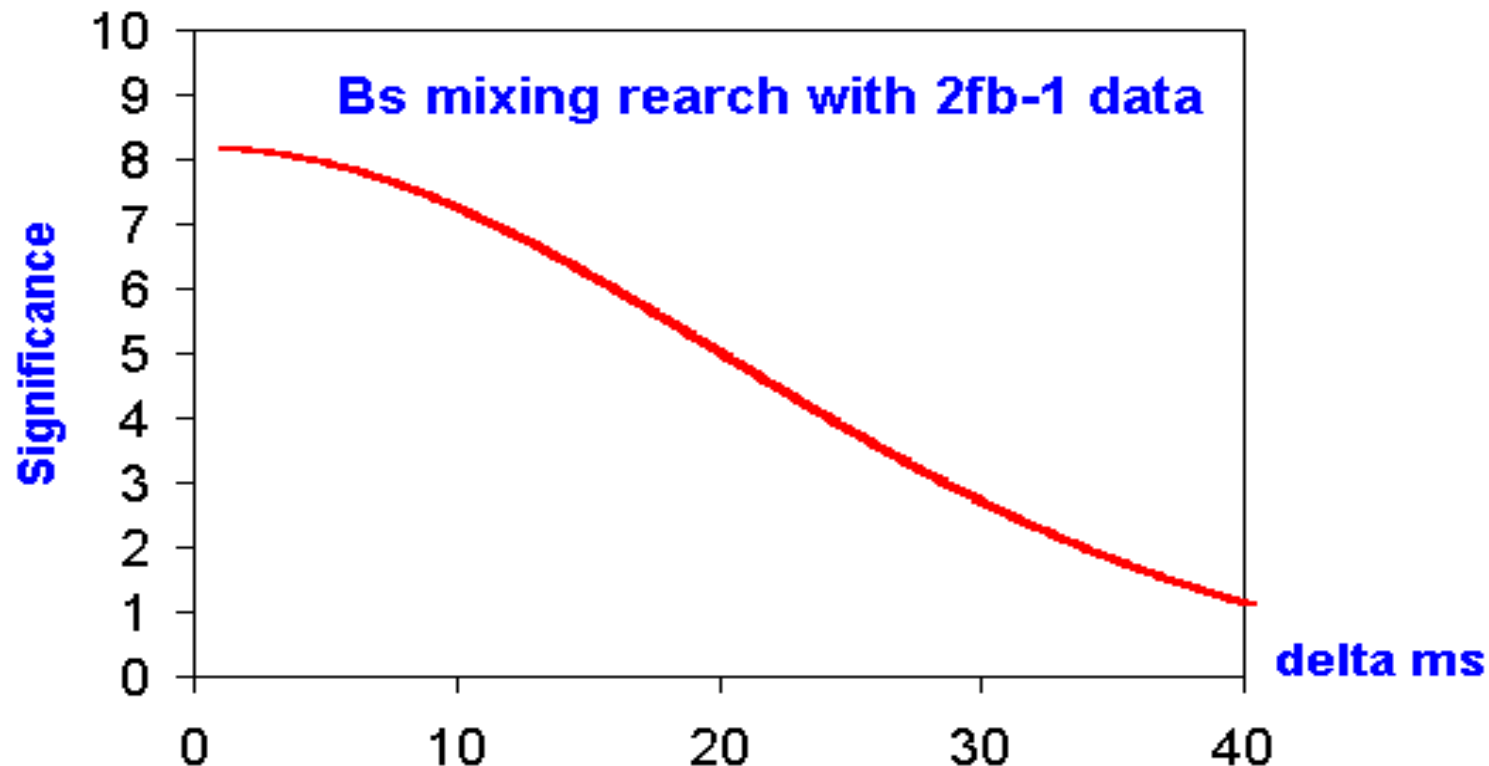
With improved TOF to enhance both SST and OKT

$\epsilon D^2 = 4\% \rightarrow 5\%$

- With L00 silicon and event-by-event beamline

$\sigma_{ct} = 0.067 \rightarrow 0.05\text{ps}$

CDF Bs mixing prospect by 2007



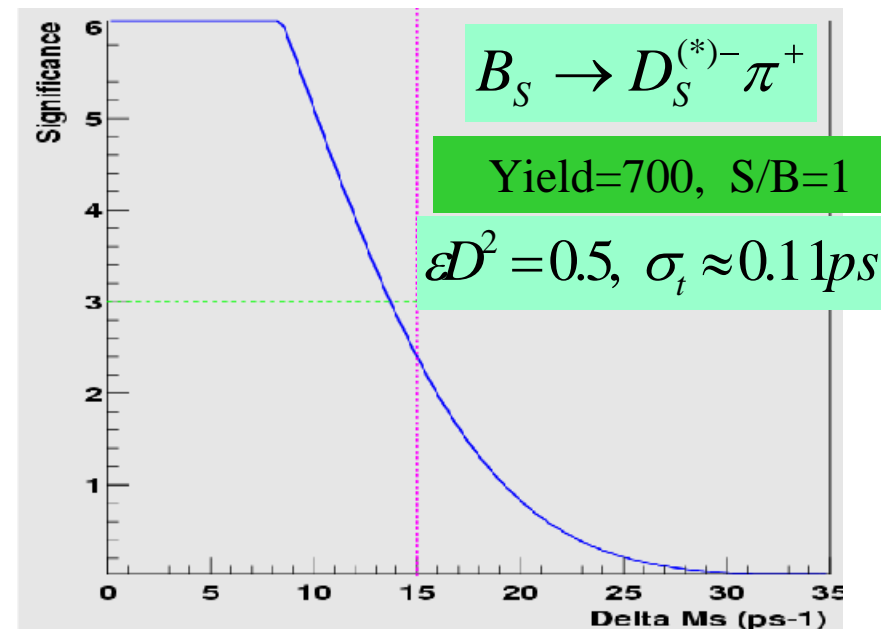
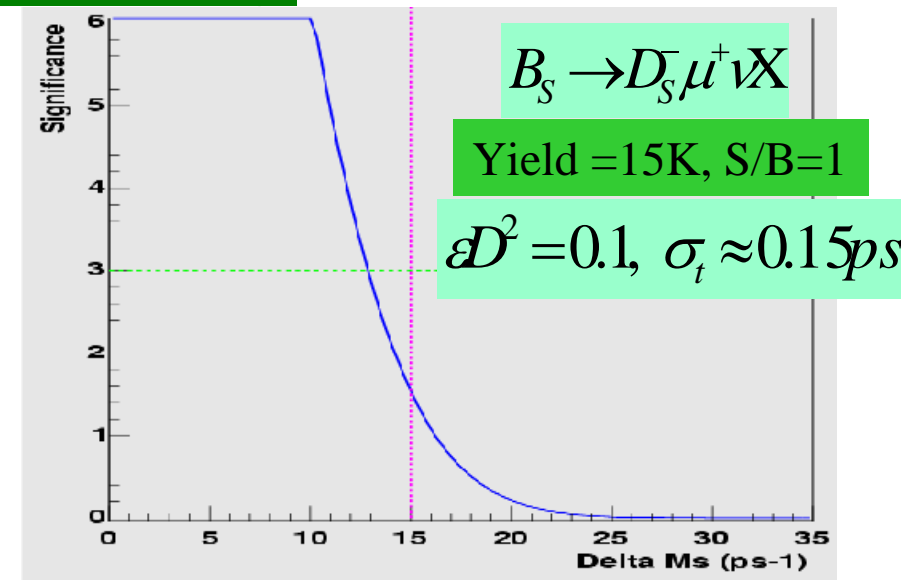
- **Go beyond standard model preferred range**

5 σ measurement if $\Delta m_s = 18 \text{ ps}^{-1}$ with 1.7fb-1 data

5 σ measurement if $\Delta m_s = 24 \text{ ps}^{-1}$ with 3.2fb-1 data

D0 Bs mixing sensitivity

- Detail in Vivek Jain's talk on Tuesday
- Projections with 500 pb⁻¹ data of inclusive muon trigger
 - Triggered muon used to reconstruct 15K $B_s \rightarrow D_s \mu \nu$
 - Triggered muon used as flavor tagger for 700 $B_s \rightarrow D_s \pi$



$\Delta\Gamma_s/\Gamma_s$ - B_s lifetime difference

- The mass difference Δm_s and lifetime difference $\Delta\Gamma_s$ of the two CP eigenstates are linked by

$$\Delta\Gamma_s/\Delta m_s = -3\pi/2 \cdot m_b^2/m_t^2 \cdot \eta(\Delta\Gamma_s)/\eta(\Delta m_s)$$

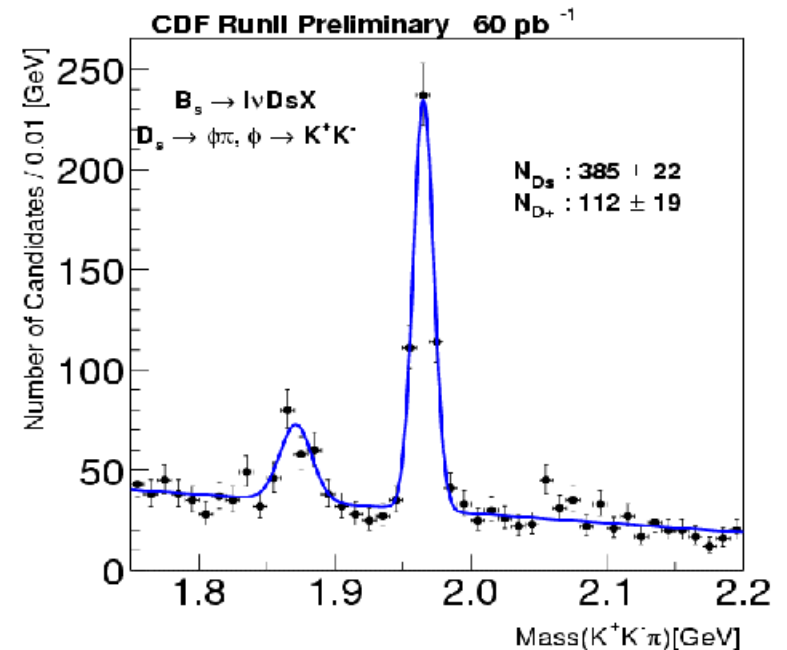
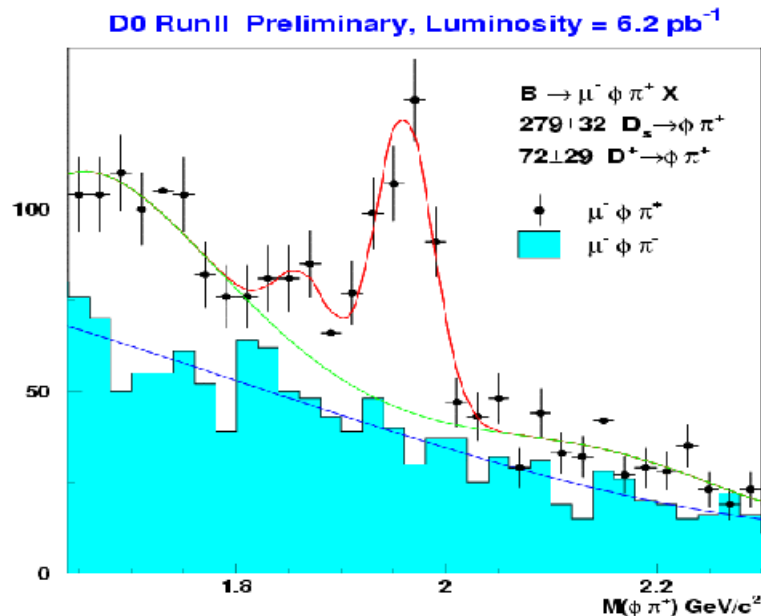
- The QCD factor doesn't depend on CKM
- Δm_s and $\Delta\Gamma_s$ measurements are complementary
- $\Delta\Gamma_s$ could be large enough to be detectable ($\Delta\Gamma_s/\Gamma_s \sim 15\%$)

$\Delta\Gamma_s/\Gamma_s$ Measurements

Three methods suggested for extracting $\Delta\Gamma_s/\Gamma_s$

- **Fitting well-defined decay with two lifetimes**
 - Fit $e^{-\Gamma_L t} + e^{-\Gamma_H t}$ for $B_s \rightarrow D_s l \nu$ or $B_s \rightarrow D_s^+ \pi^-$
- **Separate CP-even/odd states by transversity analysis**
 - $B_s \rightarrow J/\Psi \phi$ is the familiar channel to CDF/D0
- **Branching ratio from a pure CP state decay**
 - $B_s \rightarrow D_s^+ D_s^-$ a pure CP-even and triggered by CDF SVT trigger
 - $\text{Br}(B_s \rightarrow D_s^+ D_s^-) = \Delta\Gamma_s / [\Gamma_s(1 + \Delta\Gamma_s/2\Gamma_s)]$
 - Need to separate $B_s \rightarrow D_s^{+(*)} D_s^{-(*)}$ with fine mass resolution

$\Delta\Gamma_s/\Gamma_s$ from B_s semileptonic decays



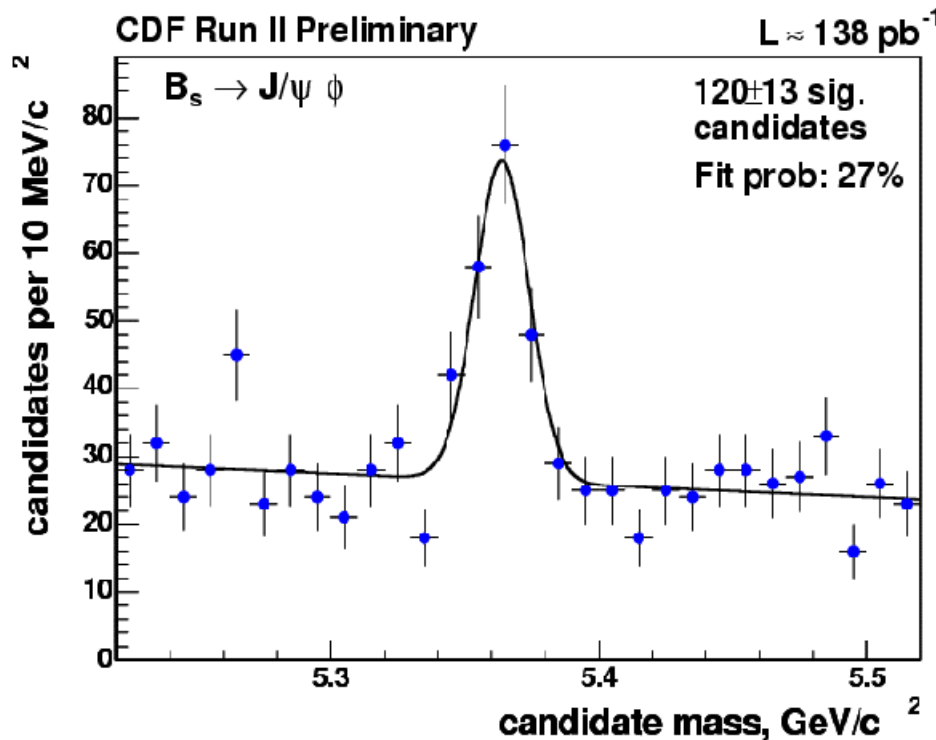
Plenty statistics from semileptonic decays

Suffer from poor lifetime resolution due to partial reconstruction

Useful for limits $\Delta\Gamma_s/\Gamma_s < 0.83$ @95% CL from 600 Run-I signals

$\Delta m_s > 5.8 \text{ ps}^{-1}$ @ 95%CL from 700 SLT-tagged Run-I signals

$\Delta\Gamma_s/\Gamma_s$ from $B_s \rightarrow J/\psi \phi$



CP states follow distributions:

$$\frac{3}{8} \cdot (1 + \cos^2 \Theta_T) \rightarrow \text{CP-even}$$

$$\frac{3}{4} \cdot (1 - \cos^2 \Theta_T) \rightarrow \text{CP-odd}$$

Θ_T = Transversity angle

Run-I with 58 events gives $\Gamma^{\text{CP-even}}/\Gamma = 0.778 \pm 0.090 \pm 0.012$

- **With 4K event \Rightarrow an error of 0.05 if $\Delta\Gamma_s/\Gamma_s = 15\%$ (Run II B workshop)**
- **CDF result with 300 events from 220pb⁻¹ is coming**

Summary

- **A lot of progress on flavor tagging from CDF/D0**
- **We are collecting $B_s \rightarrow D_s^- \pi^+$ at 1600 event/fb⁻¹**
- **With 500 pb⁻¹ data, B_s mixing measurement reaches the Standard Model preferred region ($\Delta m_s = 15 \text{ ps}^{-1}$)**
- **With 2fb⁻¹ data, B_s mixing measurement will go beyond the preferred region ($\Delta m_s > 18 \text{ ps}^{-1}$)**
- **Precise $\Delta \Gamma_s / \Gamma_s$ measurements are also underway**

Backup slides

CDF/DØ Detectors

Both detectors have very nice silicon device (lifetime), central tracking (mass) , calorimeter & muon system (e/ μ ID) and high bandwidth trigger/DAQ system

CDF

Silicon vertex trigger (SVT)

trigger displaced track and e/ μ

TOF for particle ID

2σ K- π separation at 1.5 GeV

Excellent mass resolution

DØ

Excellent muon coverage

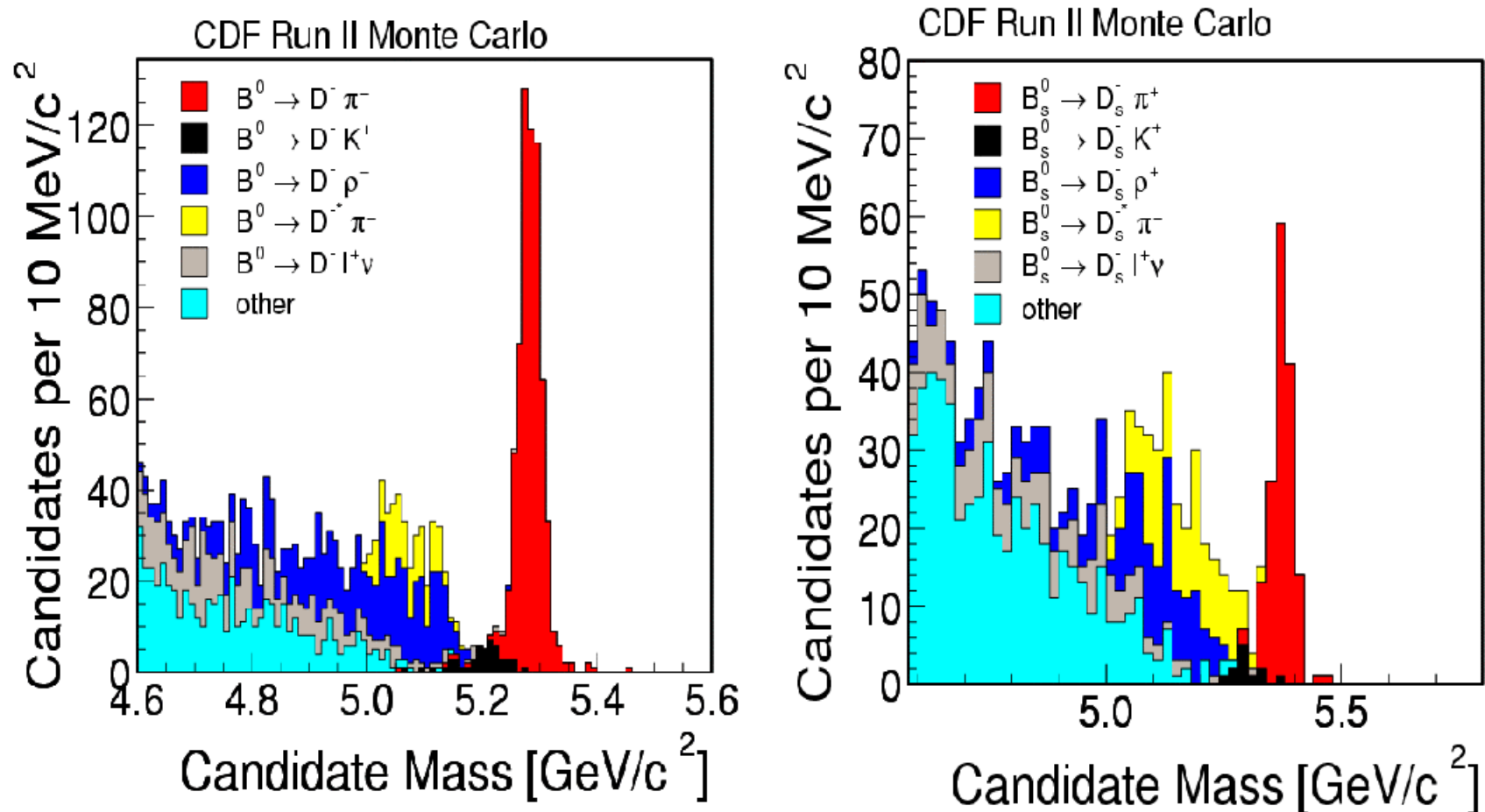
trigger μ for $p_T > 1.5$ and $|\eta| < 2.0$

Excellent tracking acceptance

SMT+SFT covers $|\eta| < 1.6$

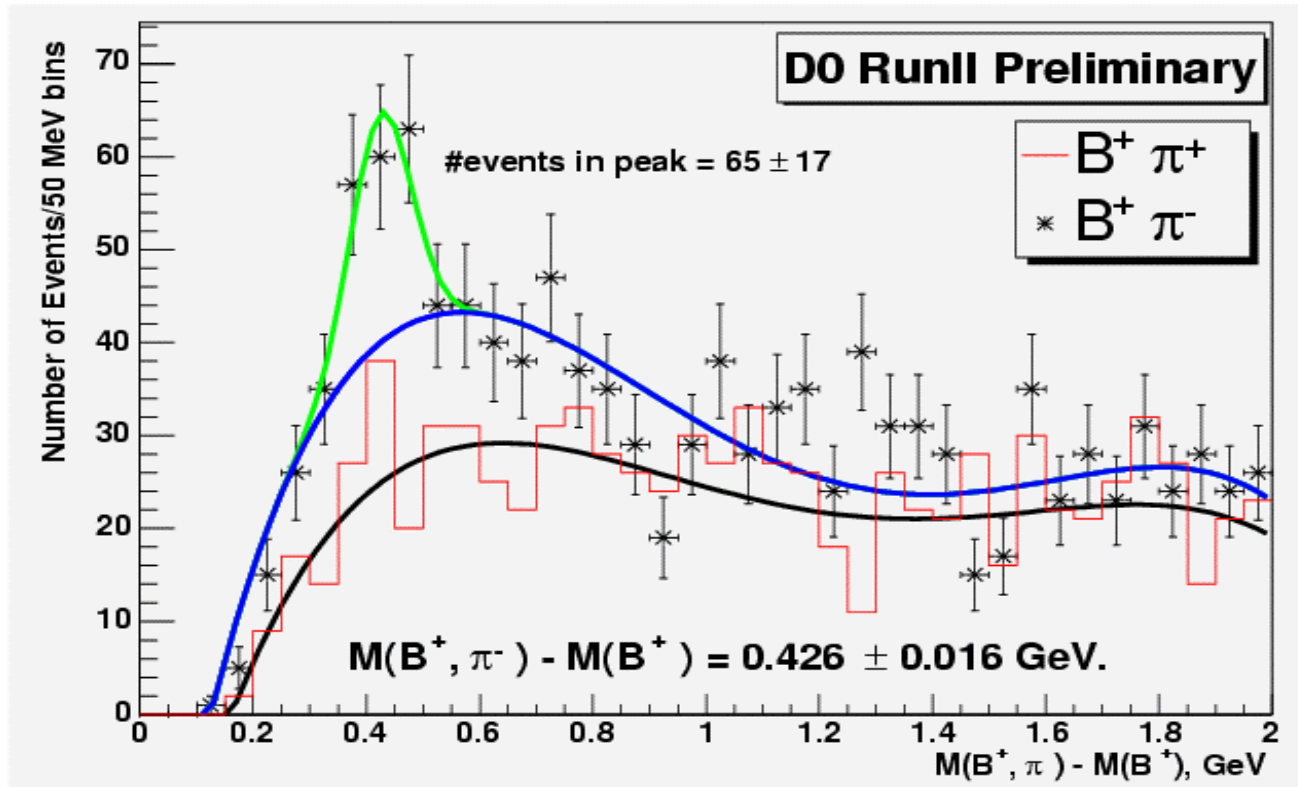
Silicon track trigger is coming

Separating $B_s \rightarrow D_s \pi$ from other B reflections



Mass resolution is crucial in achieving decent S/B

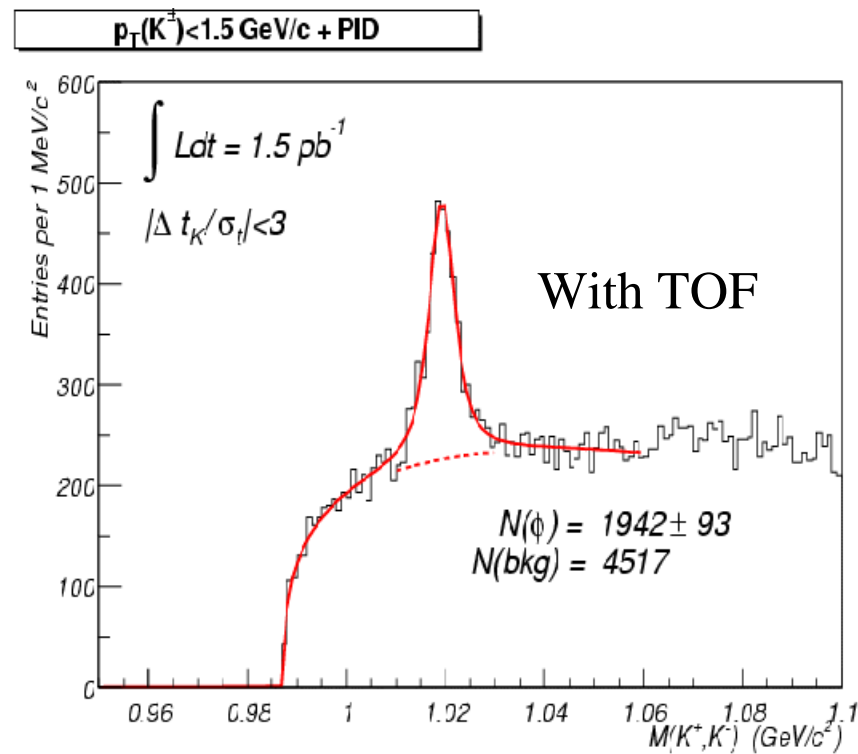
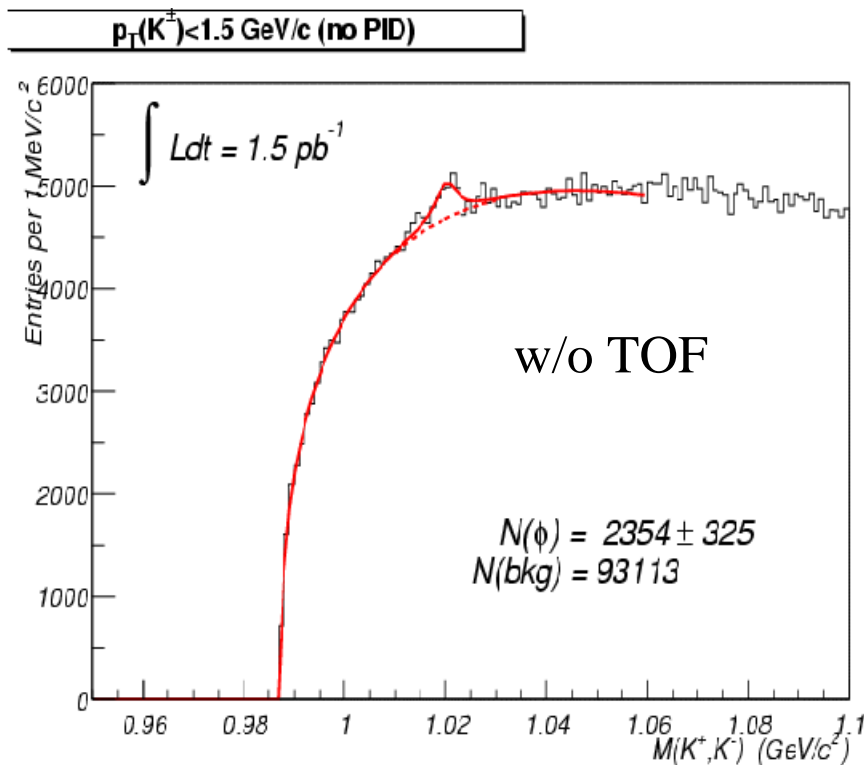
New B** result from D0



- **D0 uses fully reconstructed B+**
 - 65 ± 17 out of 1193 B could be due from $B^{*0} \rightarrow B^+ \pi^-$
- **CDF Run-I used B semileptonic decays**
 - Fraction of B from $B^{**} = 0.28 \pm 0.06 \pm 0.03$

TOF performance

- TOF is working and we are working on to improve its reconstruction efficiency



$\phi \rightarrow K K$ decays

$\Delta\Gamma_s/\Gamma_s$ from $B_s \rightarrow Ds+Ds^-$

- $\text{Br}(B_s \rightarrow Ds+Ds^-) = \Delta\Gamma_s / [\Gamma_s(1 + \Delta\Gamma_s/2\Gamma_s)]$

Theory uncertainty could be large

- Separates background of $Ds^* \rightarrow Ds \gamma$ using fine mass resolution

Also introduce 3% error on proper time

$$32 \pm 17 \text{ } B_s \rightarrow Ds^{+(*)} Ds^{-(*)} \rightarrow \phi \phi$$

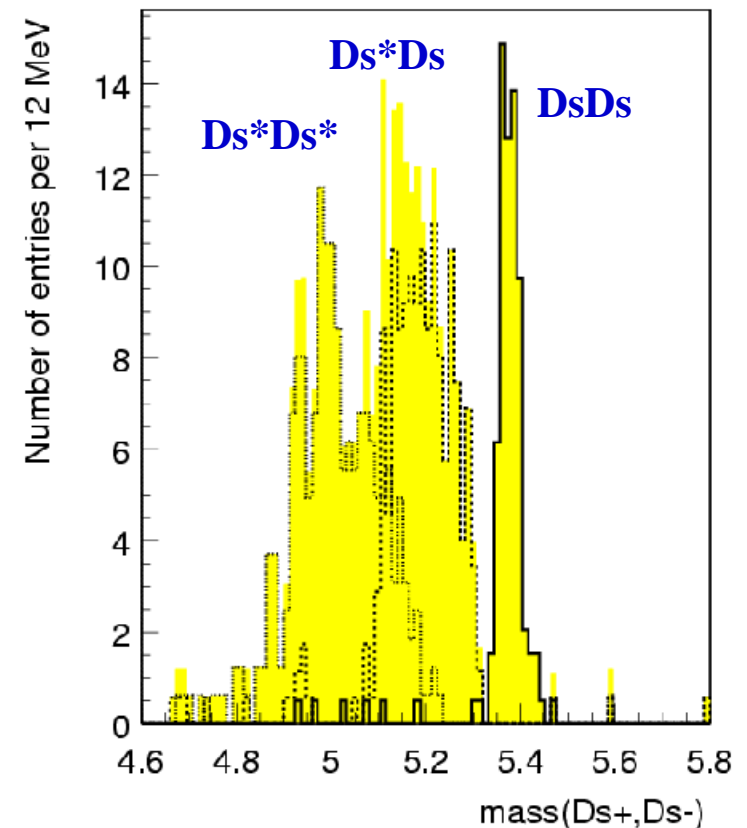
$$\Delta\Gamma_s/\Gamma_s = 0.25^{+0.21}_{-0.14} \text{ (ALEPH)}$$

- Channel is trigged with SVT of CDF

$$\text{Br}(B_s \rightarrow Ds+Ds^-) / \text{Br}(B_s \rightarrow Ds+\pi^-) \approx 2$$

Reconstruction efficiency will be lower

GEANT for CDF



(Run II B workshop)

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